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solas event report

Report 10 I August 2018

The 4th International Symposium on the Effects of Climate Change on the World Oceans

Session on: “Eastern Boundary upwelling systems: diversity, coupled dynamics and sensitivity to climate change”

2 - 8 June, 2018
Washington DC, USA

From 2 to 8 June 2018, the 4th International Symposium on the Effects of Climate Change on the World Oceans took place in Washington DC, USA, under the auspices of the International Council for the Exploration of the Sea (ICES), the North Pacific Marine Science Organization (PICES), the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO), the Food and Agriculture Organization (FAO), and the United States National Oceanic and Atmospheric Administration (NOAA), and sponsored by ICES, PICES, IOC-UNESCO, FAO, NOAA, Fisheries and Oceans Canada, COMPASS Science Communication, SOLAS, Integrated Marine Biosphere Research, International Atomic Energy Agency, Lenfest Ocean News, North Pacific Anadromous Fish Commission, Maine Coast Sea Vegetables, Monterey Bay Aquarium, Ocean Networks Canada, and Women's Aquatic Network (Figure 1). The Symposium focused on understanding and responding to climate impacts on ocean systems. The Earth’s climate and oceans are rapidly changing, the impacts are already evident in some regions and more impacts are expected with continued changes in the

In this report

Attendees research profiles

Figure 1: The ECCWO sponsor list at the Symposium venue. © Véronique Garçon

planet's climate system. There is much at stake. Future efforts to find solutions will include lessons learnt from the symposium to stimulate future science and to inform a range of societal options as people continue to adapt, adjust, and respond to these changes in the world's oceans.

The Symposium included invited plenary sessions, contributed paper sessions with extended periods for discussion, and workshops that explored topics in greater depth. A suite of theme sessions provided opportunities for scientific exchange within disciplines, as well as forums for the integration of knowledge of climate impacts from physics to society (e.g. from physical processes and their interaction with ecosystem dynamics, to food provision and ocean governance). Other theme sessions focused on comparing observed and projected changes in physical and chemical oceanography, the associated changes in the productivity, distribution, ecology and phenology of species, and the impacts of these changes on marine ecosystem structure and function, fisheries, and other socio-ecological systems. These included comparisons within a system under different scenarios and/or between systems under common scenarios. The Symposium has advanced understanding of the vulnerability and resiliency of ocean ecosystems and ocean-dependent human communities in a changing climate, and thereby informed societal consideration of risks, opportunities and actions concerning the world's oceans.

The Symposium in a few take home messages:

- The oceans and the social-ecological systems that depend on them are changing.
- Our understanding of social-ecological systems has improved allowing us to contrast the ecological and human impacts of different future scenarios. Opportunities for adaptation are more limited if society remains on a high emission scenario.
- Tactical and strategic opportunities for adaptation to climate change have been revealed through engagement.
- Extreme events provide an opportunity to assess human and ecological responses to climate change. Our ability to predict anomalous ocean conditions on seasonal to decadal time scales is improving.
- Research continues to reveal complex energetic and physiological trade-offs associated with adaptation to changing environmental conditions. There are energetic and physiological costs to adaptation that must be recognised.
- Coastal communities are turning to aquaculture, marine ranching, and fish attraction technologies to fill critical needs for food security. Research is needed to identify appropriate adaptation actions and good governance through stakeholder engagement and representation.
- Blue carbon solutions are emerging.
- More targeted measurements are necessary to better understand the oceanic carbon cycle and minimise uncertainties for both short-term prediction and long-term projection of the carbon uptake, ocean acidification, and

ocean deoxygenation. Global Observation networks with technological advancements for data collection will improve our understanding of key processes.

- International planning and assessment activities play a key role in guiding and informing our research.

The Symposium in numbers:
669 registrations, 51 countries, 18 sessions, 11 workshops and 3 Town Halls, 350 oral presentations, 158 posters, 102 students….and 4,103 tweets and 2,866 re-tweets!

All plenaries can be viewed at：
https://meetings.pices.int/publications/video#2018-ECCWO

SOLAS themes were covered by a couple of sessions but we would like to focus here on Session 7 entitled “Eastern Boundary upwelling systems: diversity, coupled dynamics and sensitivity to climate change”, co-chaired by Ivonne Montes (Corresponding Chair, Instituto Geofísico del Perú, Perú) and Ryan Rykaczewski (Department of Biological Sciences and Marine Science Program, University of South Carolina, USA). The Eastern Boundary Upwelling Systems (EBUS) are the most productive areas of the world’s oceans, supporting large populations of commercially important fish species. The basic forcing mechanisms are similar across the different EBUS. However, owing to differences in the relative strengths of potential stressors, a unified understanding regarding the sensitivity of individual EBUS to climate change remains evasive. In this session, talks on the different physical mechanisms occurring over different time scales (i.e., intradaily, intraseasonal, interannual, decadal, multidecadal) and their implications for water-column properties, biogeochemical cycles, biodiversity/ecosystem structure and functioning, and the regional climate in various EBUS were presented. Key feedback processes in EBUS, similarities and differences across systems and critical knowledge gaps that limit our current understanding of physical and ecological responses to natural and anthropogenic climate forcing in EBUS were discussed.

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CNRS/LEGOS, France, one of the four Symposium convenors

Rodrigue Anicet Imbol Koungue is from Cameroon. He studied Physics in Cameroon at the University of Yaoundé. He moved to Benin for his Master studies in Physical Oceanography at the University of Abomey-Calavi in Cotonou. Rodrigue Anicet joined the Department of Oceanography at University of Cape Town, South Africa, in September 2014 to start his PhD project which is funded by the Nansen Tutu Centre. He investigated the triggering mechanisms associated with the occurrences of coastal extreme warm and cold events along the Angola-Namibia coastline from 1998 to 2012 under the supervision of Prof. Mathieu Rouault and Dr. Serena Illig.

Role of Interannual Kelvin wave propagations in the equatorial Atlantic on the Angola Benguela current system from 1998 to 2012

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The Benguela Upwelling System (BUS) is one of the most productive marine ecosystems in the world, supporting a large marine ecosystem. Compared to the other Eastern Boundary Upwelling Systems (EBUS), one specific feature of the BUS is that it is encircled by warm waters at its northern and southern boundaries: tropical waters from the equatorial Atlantic in the north and warm-waters coming from the Agulhas current in the south. This is well observed in Figure 2 which illustrates the Sea Surface Temperature (SST) and wind stress in austral summer in the southeast Atlantic Ocean.

The BUS undergoes important variability at a wide range of frequencies and in particular at interannual timescales. Every few years, the BUS is indeed subject to the intrusion of anomalously warm waters from the tropical Atlantic. These events are called Benguela Niños (Shannon *et al.,* 1986) and are represented in Figure 3a. Benguela Niños typically manifest along the coast of Angola and Namibia in the southeast Atlantic Ocean. These anomalously warm events tend to reach their maximum during the late austral summer mainly during March-April and originate from the relaxation of zonal wind stress in the equatorial Atlantic in January-February (Florenchie *et al*., 2004). During a Benguela Niño event, the SST can peak up to 4°C above the seasonal average. The cool phase of Benguela Niño is called Benguela Niña (Figure 3b). Benguela Niños and Niñas are of great socio-economic importance for the countries of Southern Africa due to their impacts on climate, rainfall, marine productivity, and fisheries in the BUS. The forcing mechanisms responsible for the interannual variability of SST in Angola-Benguela current system are still under debate. Two main forcing factors are identified in the literature: Firstly, the local atmospheric forcing mainly explained by variations in the coastal wind stress along the coast of Angola and Namibia (Richter *et al.,* 2010). Secondly, the remote oceanic forcing associated with the propagation of Interannual Equatorial Kelvin Waves (IEKW) along the equatorial Atlantic, which then, at the African coast, propagate poleward as Coastal Trapped Waves (CTW) (Bachèlery *et al.,* 2016; Imbol Koungue *et al.,* 2017). One of the key objectives of this study was to investigate the connection between the linear dynamics in the equatorial Atlantic and the coastal variability off Angola-Namibia from 1998 to 2012.

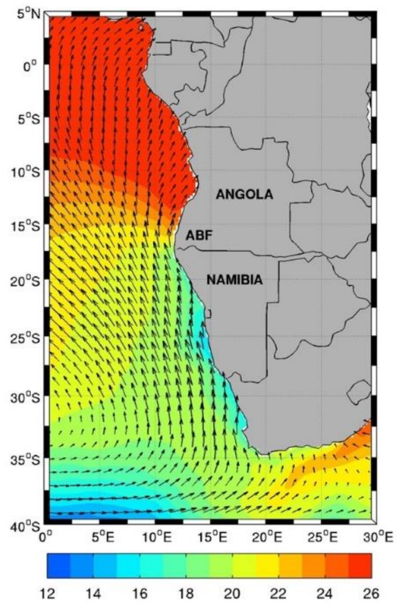

Figure 2: Left panel: AVHRR SST and SCOW wind stress averaged in austral summer (October to March) from September 1999 to October 2009.

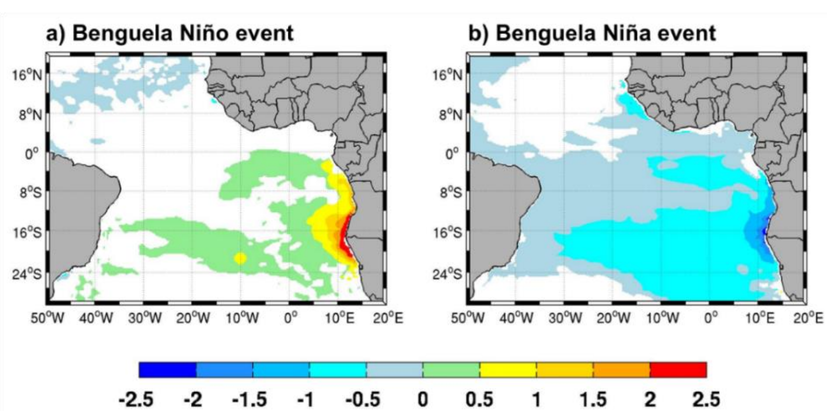

Figure 3: Composite maps of detrended anomalies of surface temperature (in colour, in °C) computed in March – April from: a) 5 selected extreme warm coastal events and b) 5 extreme cold coastal events. The shaded areas (detrended anomalies of T10) represent the 90% statistically significant areas.

Thereforediction and Research Moored Array in the Tropical Atlantic (PIRATA) buoy measurements were used to define an index of IEKW activity in combination with altimetric monthly Sea Surface Height Anomalies (SSHA) and SSHA calculated with a simple Ocean Linear Model. This IEKW index appears to be a skilful proxy to forecast coastal warm and cold events by about one month between October and April.

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Nele Tim, meteorologist by training, finished her PhD in 2015 at Helmholtz-Zentrum Geesthacht on the atmospheric drivers and variabilities of the Benguela upwelling system. Currently, she is working as PostDoc at the University of Hamburg on the impacts of the Agulhas Leakage on the central water masses in this upwelling.

Origin and pathways of the central water masses in the Benguela upwelling system and the impact of the Agulhas leakage

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We analyse the origin, pathways, and age of the central water masses in the Benguela upwelling system (BUS) and the contribution of the Agulhas leakage to upwelling water masses in a high-resolution ocean simulation. The Agulhas Current flows along the east coast of southern Africa transporting warm and saline water southwestward. At the southern tip of the African continent, a small fraction (Agulhas leakage) leaves the Agulhas System and continues westward into the Atlantic Ocean (Gordon, 1986). The BUS, located off Southwest Africa, is one of the four important Eastern Boundary Upwelling Systems (EBUS) (Figure 4a) where trade wind induced

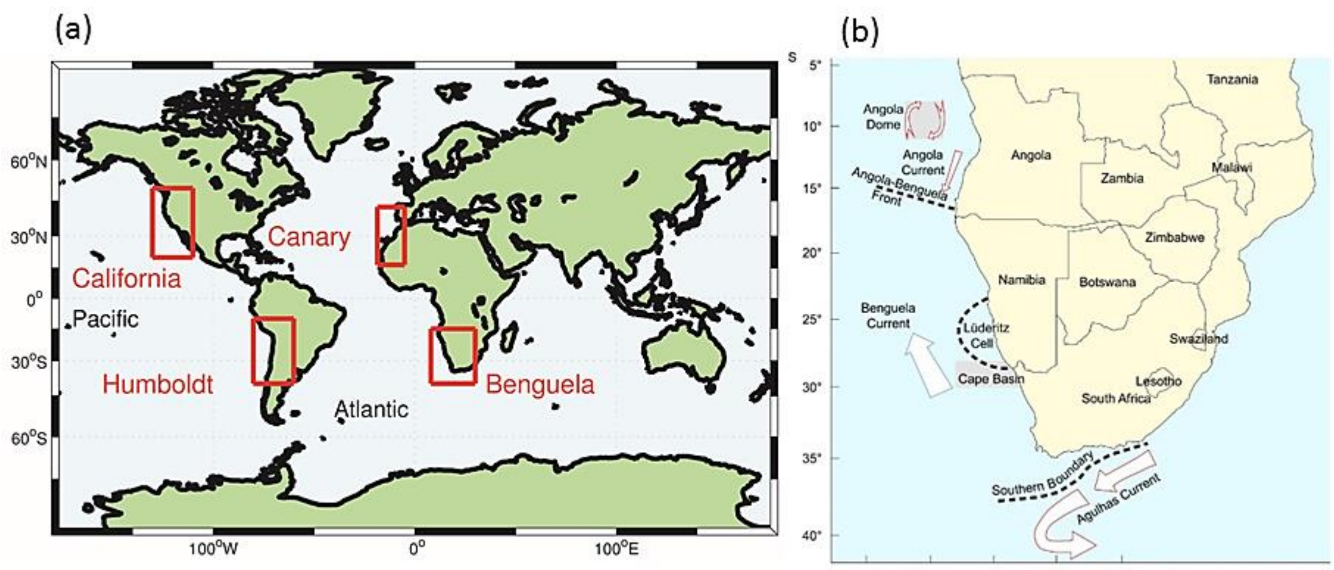

Figure 4: (a) Areas in red show the location of the four Eastern Boundary Upwelling Systems. (b) Schematic map of the Benguela upwelling system (Tim, 2016).

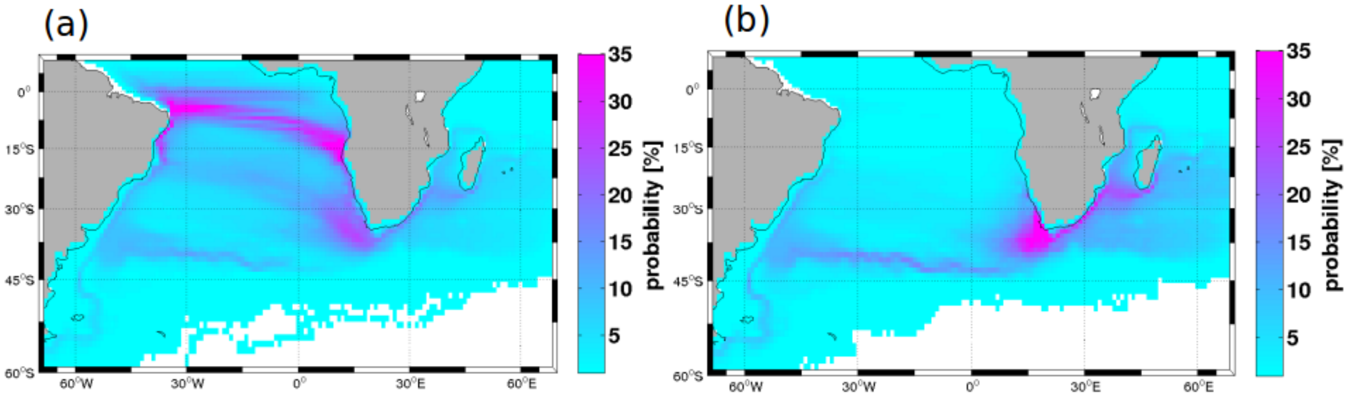

Figure 5: Percentage of parcels seeded in North Benguela (a) and South Benguela (b) calculated backward that pass a 1° grid box at least once during the simulation period (1958-2009).

upwelling of cold nutrient-rich water favours biomass growth. The BUS is separated at 27°S by the Lüderitz upwelling cell into North and South Benguela (Figure 4b) (Tim *et al.,* 2015). The water masses in the two subregions differ in nutrient and oxygen properties.

Observational studies (Mohrholz *et al*., 2008; Poole and Tomczak, 1999) suggest that the central waters of South Benguela are dominated by Eastern South Atlantic Central Water (ESACW), whereas South Atlantic Central Water (SACW) dominates in North Benguela. The SACW forms in the Brazil-Malvinas Confluence Zone (BMCZ) in the western South Atlantic. The ESACW forms when Agulhas leakage water mixes in the Cape region with the SACW. ESACW enters South Benguela rather direct, whereas the SACW takes a longer route through the equatorial current system before reaching North Benguela.

We test this hypothesis in a hindcast experiment (1958-2009) with the global nested ocean-only configuration INALT20 of the NEMO model (Madec, 2008). INALT20 has a global base model (ORCA025 (Barnier *et al*., 2006)) with a horizontal resolution of 1/4° and a nest over the South Atlantic and the western Indian Ocean with a resolution of 1/20°. In the nest, the simulation is eddy-resolving leading to a realistic simulation of the greater Agulhas system. Contributions, pathways, and age are studied with Lagrangian analysis of the trajectories of water volumes advected with the simulated ocean currents.

Our analysis shows that the Agulhas Current contributes more strongly to the central water masses in the BUS than the subduction region in the BMCZ. The contribution of Indian Ocean water is 70% of the water mass in South Benguela, and even 48% in North Benguela. The remaining percentages of the water masses originate from the BMZC (~25% for both regions) and only 1% for South Benguela, but 25% for North Benguela from the North Atlantic.

Furthermore, our study confirms the hypothesis based on observations that the central water masses in the North and South Benguela differ in their pathways into the upwelling regions: North Benguela SACW enters the upwelling region mainly by the equatorial current system, with only a small portion crossing the boundary between the two subsystems (Figure 5a) whereas ESACW flows directly with the Benguela Current into the upwelling region (Figure 5b). These different pathways lead to differences in water age and associated biogeochemical properties.

The location of last mixed-layer contact for both water masses is mainly in the Cape Basin. Thus, ESACW is younger than SACW with age of 6 years as travel times from last ventilation to North Benguela are twice as long. This leads to higher oxygen utilisation, carbon dioxide (CO_2) and nutrient build-up from remineralisation of sinking organic matter in SACW than in ESACW. Thus, the distinct pathways cause age difference, with in turn can help explaining the contrasting nutrient, CO_2, and oxygen properties of the upwelling water masses in the North and South Benguela (Emeis *et al.*, 2017).

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Carlos Conejero studied geophysics at the University of Concepcion, Chile. He started his PhD in 2017 at LEGOS, France, to investigate the impact of climate change on the oceanic circulation in the Eastern Boundary Upwelling Systems of the South Hemisphere.

Mechanisms associated to the global warming-induced sea surface temperature pattern in the South Eastern Pacific

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The Eastern Boundary Upwelling Systems (EBUS) are of particular interest because they connect the tropical ocean basins with the mid-latitudes. These regions share common characteristics (i.e. upwelling favourable winds, Figure 6) and contain very productive oceanic ecosystems and fisheries. The Humboldt System located in the South Eastern Pacific (SEP) is the most productive EBUS. Understanding how global warming will modify the oceanic circulation in this region remains a scientific challenge. Coupled Model Intercomparison Project (CMIP) -class models predict stronger warming in the equatorial region compared to the mid-latitudes of the South Hemisphere, resulting in a differential warming rate in the EBUS between the coastal and the off-shore ocean (Meehl *et al*., 2007).

In the SEP, the enhanced equatorial warming relative to the subtropics has been linked to changes in latent heat loss, negative shortwave

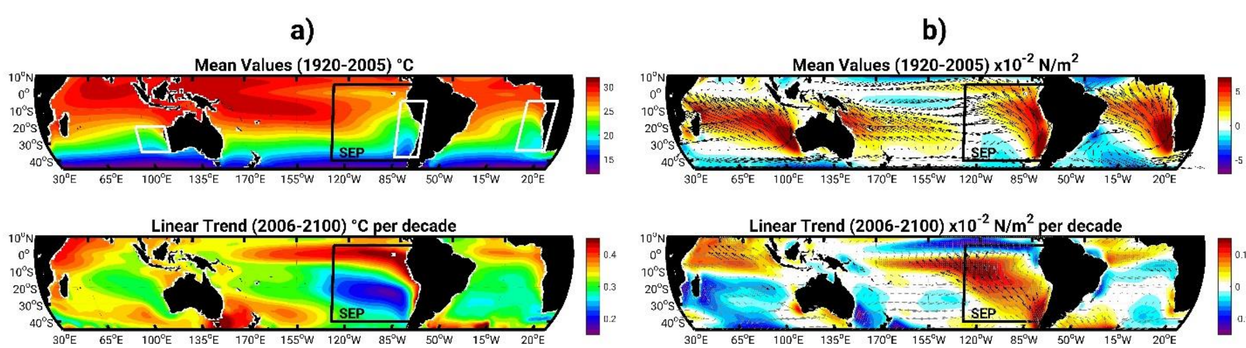

Figure 6: CESM-LENS 40 mean-ensemble of a) sea surface temperature, and b) meridional wind stress component. Mean values (linear trend) correspond to historical (RCP8.5) runs in upper (lower) panels. White rectangles correspond to the Eastern Boundary Upwelling Systems of the South Hemisphere and black rectangle indicates the South Eastern Pacific (SEP) region. Black vectors in b) correspond to wind stress.

cloud forcing, and ocean mixing (Liu *et al*., 2005) or changes in the southeast trade winds through the wind-evaporation-sea surface temperature (WES) feedback (Xie *et al*., 2010), suggesting that the role of ocean dynamics is minor. In addition, the mechanism involved in the minimum warming rate in the subtropics is yet to be elucidated.

Here we investigate the processes associated to the sea surface temperature (SST) climate change pattern in the SEP based on the Community Earth System Model Large Ensemble (CESM-LENS, Kay *et al*., 2015). To disentangle the complex of processes acting on SST, we carried out a heat budget analysis of the mixed layer (fixed at 50 m depth) associated to the long-term SST trend over the period 2006-2100 considering advection. We decomposed the tendency term associated to latent heat flux into a Newtonian cooling (αQLHm), wind speed, relative humidity and stability effects derive.

The SST trend pattern in the CESM-LENS simulations for which the radiative forcing levels yield 8.5 Wm^{-2} by 2100 (Representative Concentration Pathways (RCP) 8.5 scenario) consists in a region of minimum warming rate (~0.2°C/decade) off Central Chile that extends from the coast up to 130°W and between 40°S and 10°S. The warming rate is twice as large in the eastern equatorial Pacific and near the coast of Peru and Chile (Figure 6a). This pattern of minimum warming can be understood to the first order as resulting from the mean pattern of latent flux, which imposes that the SST tendency is minimum where the later is maximum, controlling the ocean's ability to limit SST warming by evaporation (αQLHm). However, the minimum warming is found at ~10°S to the south of the location of mean latent heat (Figure 7).

The heat budget analysis reveals that south of 10°S, the SST trend can be explained to a large extent by the summed-up contribution of heat flux and advection. Advection consists in a warming trend that compensate the excessive relative

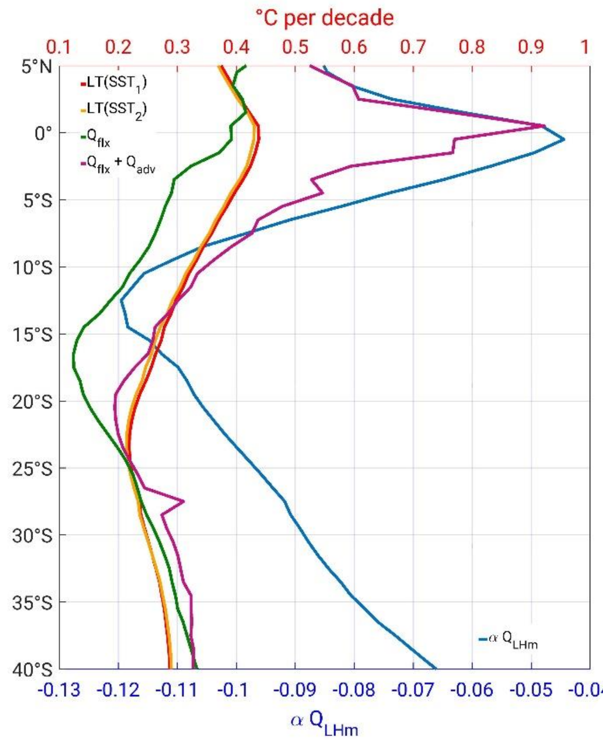

Figure 7: CESM-LENS 40 zonal mean-ensemble in the SEP region to Newtonian cooling coefficient (blue line, αQLHm) from mean value 1920-2005, and linear trend (°C per decade) from RCP8.5 runs to sea surface temperature directly from model (red line, LT(SST1)), SST from our heat balance (orange line, LT(SST2)), surface heat fluxes (green line, Qflx), and surface heat fluxes plus ocean heat advection (purple line, Qflx+ Qadv).

cooling by evaporation that is found north of 25°S so that the minimum warming rate is found around 24°S instead of 17°S if ocean advection was null. The warming trend of the advection term is associated to the meridional Ekman current owned to the increased in the southeast trade winds.

Our results suggest that the global warming pattern in the SEP is formed through the combined effect of the radiative forcing and the changes in the surface circulation associated to the expansion of the Hadley cell.

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